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In High Energy Physics

Jet Energy Reconstruction with the CMS detector

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(for the CMS collaboration)

Outline of talk

Calorimeter response to single pion

Jet energy corrections
- simple correction with mapping
- using tracks

Extensions to MET (missing E_T)

Conclusions

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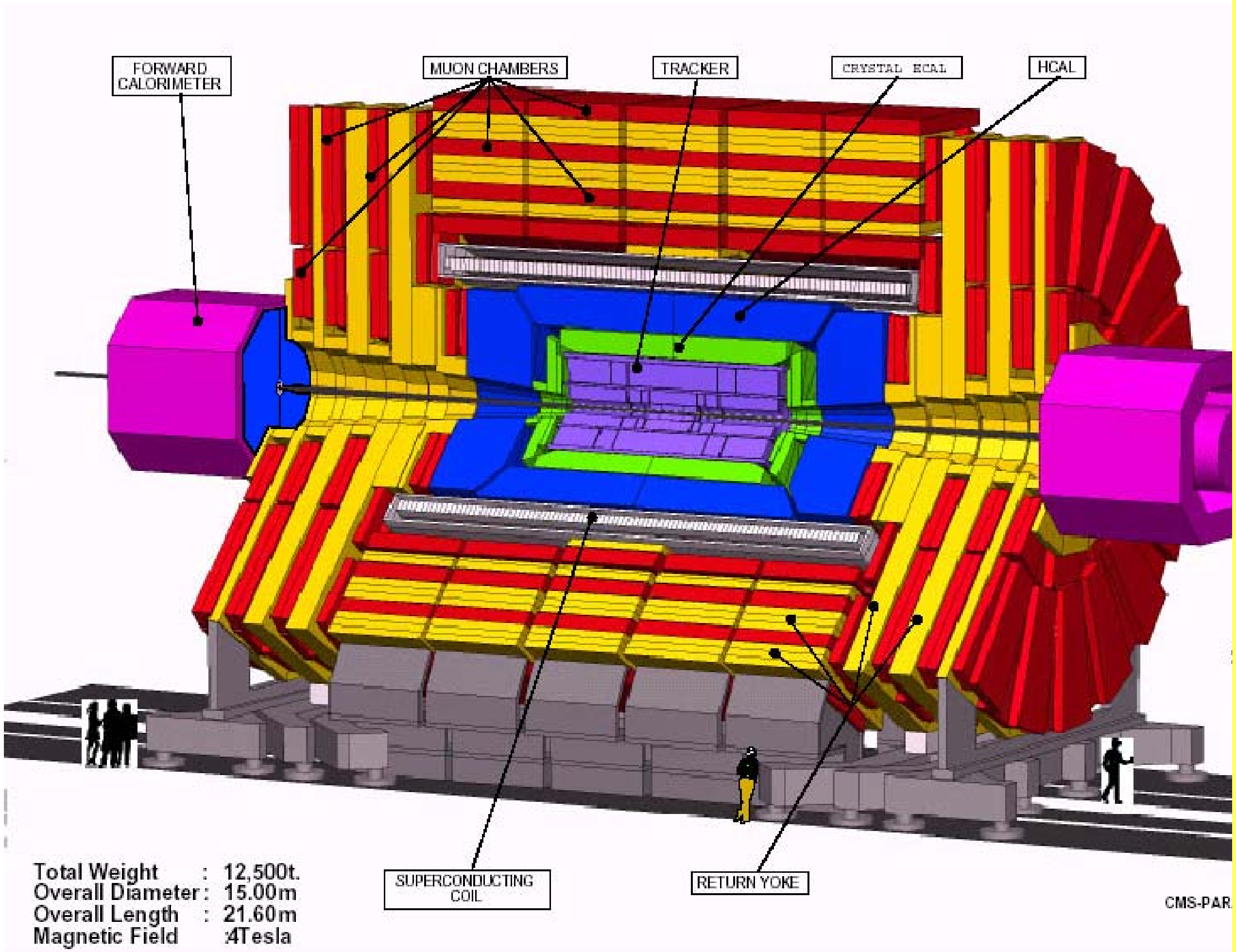
CMS Detector



Tracker
All silicon
$|\eta|<2.4$

ECAL
PbWO4 crystals
e/h ~ 1.60
$|\eta|<3.0$

HCAL (barrel/endcap)
Scint-tile & brass sampling
e/h ~ 1.39
$|\eta|<3.0$

– 4 Tesla field –

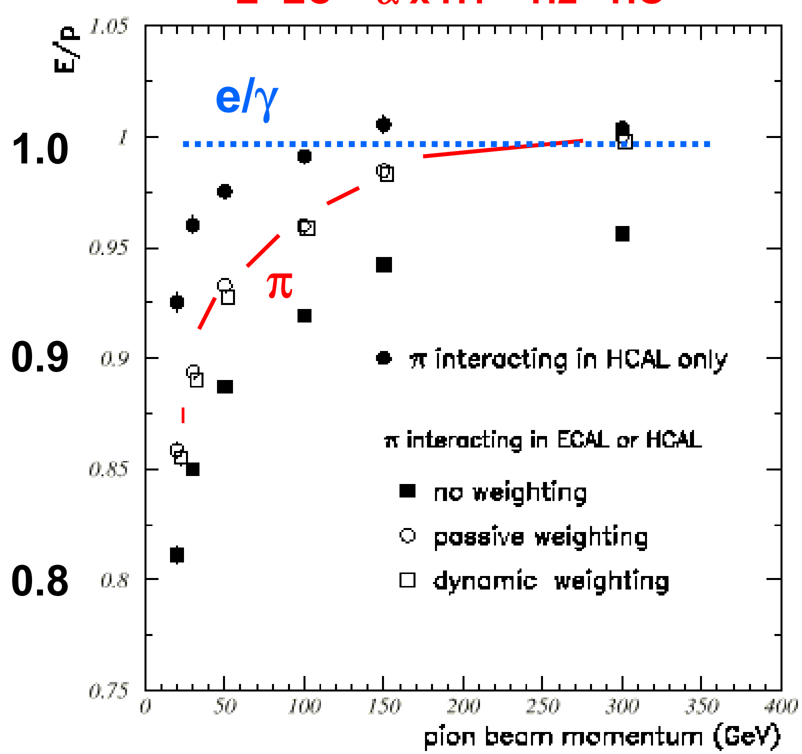
HCAL (fwd)
Quartz-fiber & iron
$3.0<|\eta|<5.0$

Pion Response: Linearity

ECAHL+HCAL: Non compensating calorimeter

96'H2 Teast Beam Data

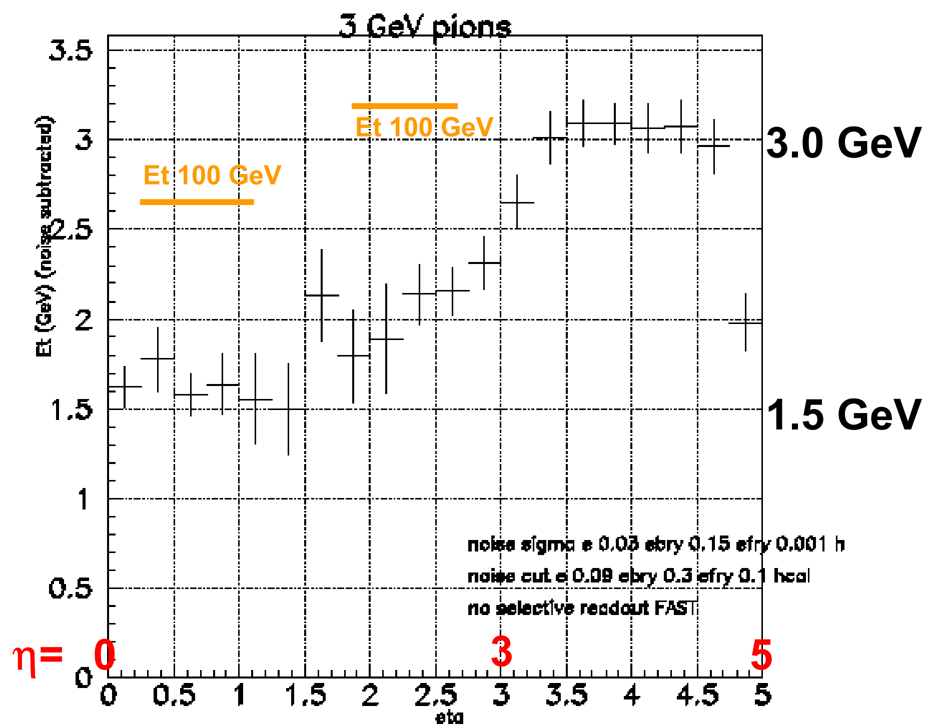
E=EC + α x H1 + H2 +HO



P= 0 200 400GeV

CMS Simulation

P_T=3 GeV pion in 0<|η|<5

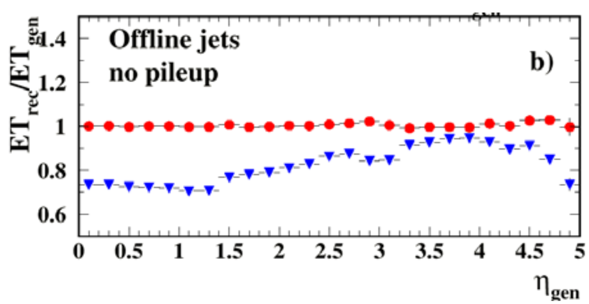


P= 3 7 30 82 227 GeV

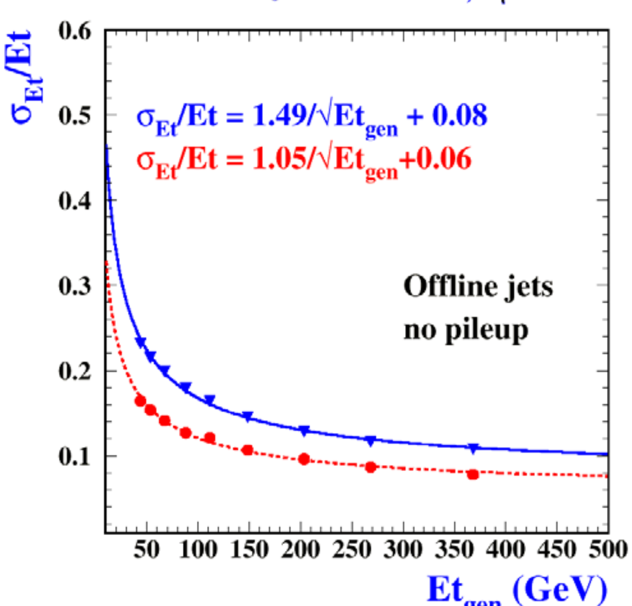
Simple Jet Energy Correction (#1)

Map of response in E_T-η: $E_T(\text{corr}) = a + b \times E_T(\text{raw}) + c \times E_T(\text{raw})^2$

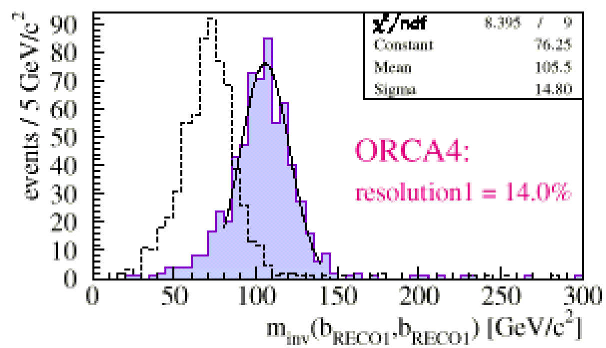
a,b,c depends on E_T and η



Offline Jets resolution, $|\eta|<5$



M(bb) in ttH



Jet energy correction

without: 19%

with: 14%

→ Level 1 trigger, HLT trigger, offline

Jet Energy Correction

Jet Energy Correction

Correction for detector effects

e.g. Calorimeter jet (cone R<0.5) → Particle level jet (cone R<0.5)

(Not for physics effects, e.g. final state radiation etc.)

Algorithms:

- **Jet based**

1) $E = a \times (EC+HC)$, a depends on jet(E_T,η)

baseline: implemented in both trigger & offline.

2) $E = a \times EC + b \times HC$, a, b depend on jet($E_T$,$\eta$)

Note: no longitudinal segmentation in ECAL (1.1λ) and HCAL

- **Cluster based**

3) E = em + had (using calo only)

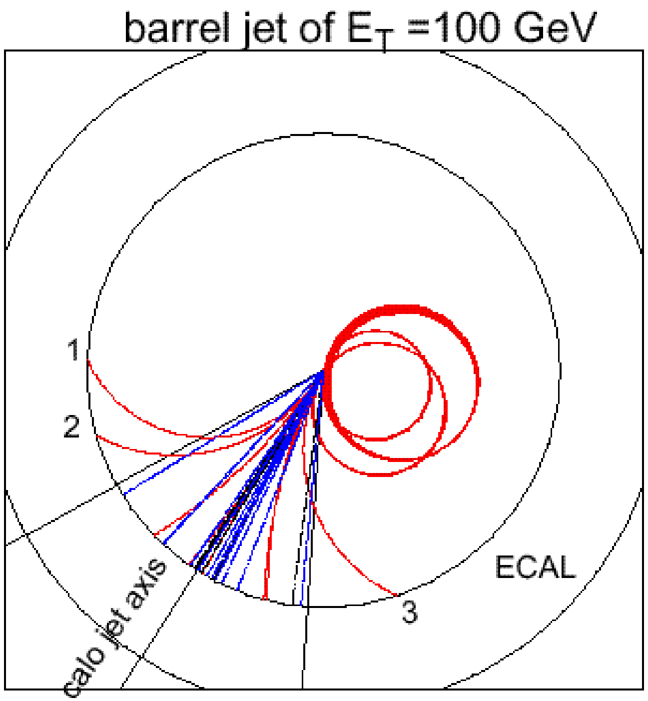
Calib. coefficients to em-cluster and had-cluster, separately.

- **Use of reconstructed tracks**

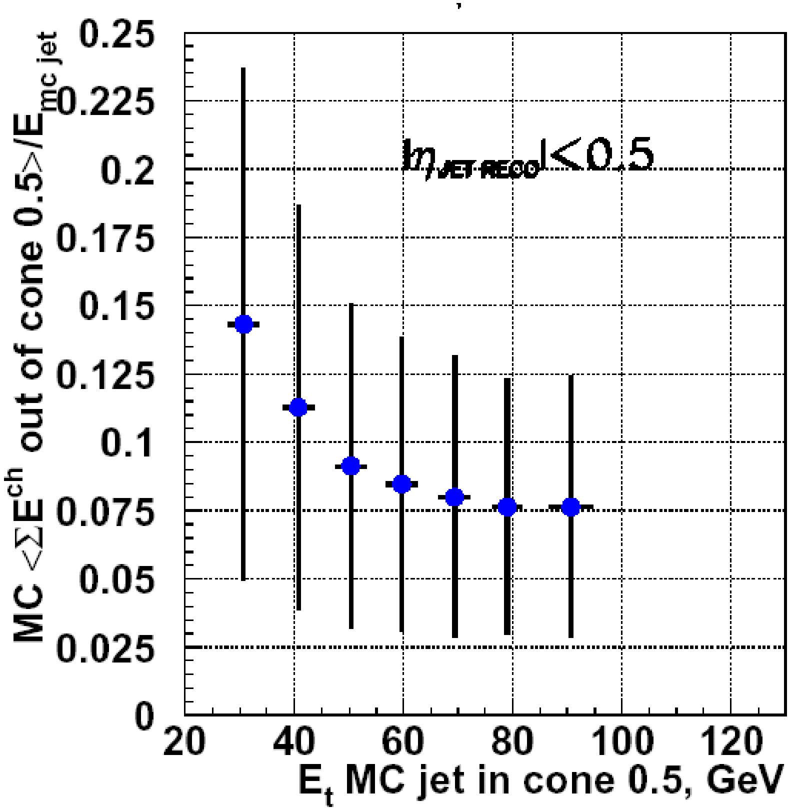
4) $E = E_0$ + (Tracks swept away by 4T field)

5) $E = EC(e/\gamma) + (EC+HC)$(neutral.h) + Tracks(charged.h)

Effect of 4 Tesla Filed



Fraction of energy escape from a jet cone (R=0.5) in 4T field.



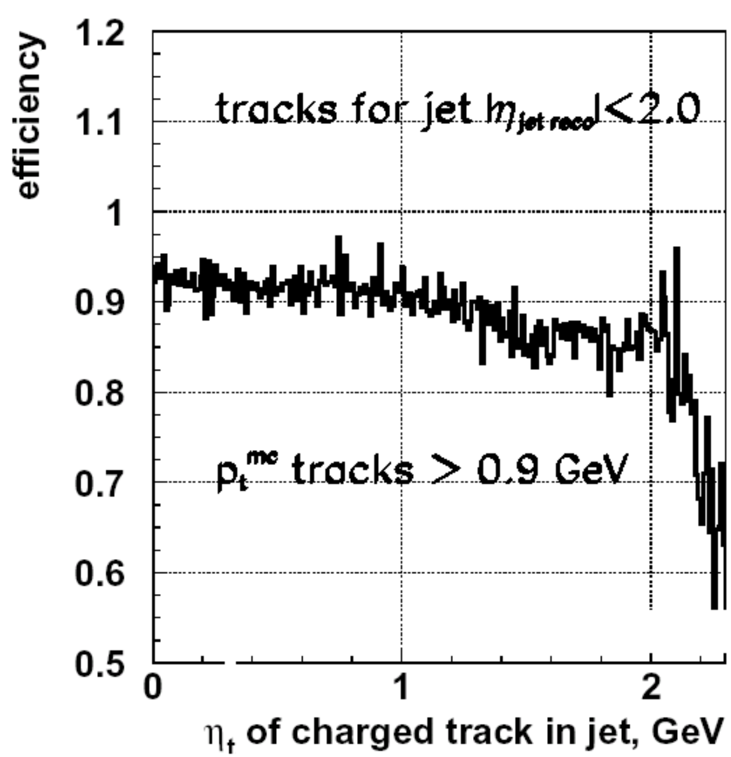
Radius of ECAL front ~ 1.3 meters

Charged particles P_T < 0.8GeV
→ Looper in barrel.

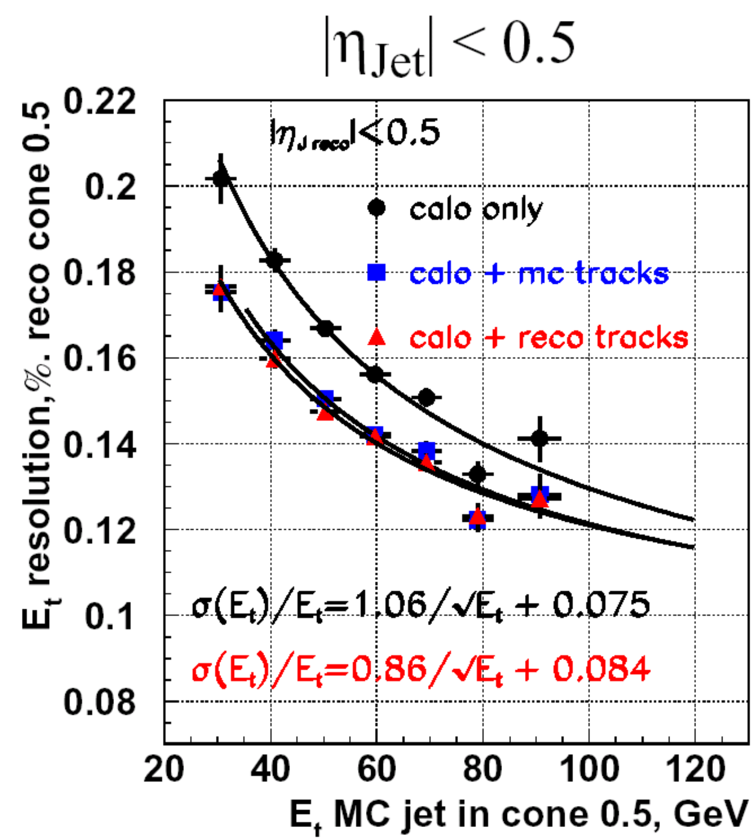
Correction to B-field effect (#4)

Add energy of charged tracks swept away from jet cone (R=0.5) by 4T field.

Track reconstruction efficiency by ORCA (CMS reconstruction program)



Improvement of resolution



Correction using Tracks (#5)
"energy flow"

$E(corr) = E(calo) + \Delta E(\text{out-of-cone tracks}) + \Delta E\ (\text{in-cone tracks})$

corr. for 4T field — corr. for calo response

For each track inside jet cone:

Form a cluster around track: 3x3 crystals + 3x3 HCAL

in $\eta x\phi$: $(0.017x3)^2 + (0.087x3)^2$

Track – Cluster match: $-\sigma < E_{track} - E_{cluster} < 2\sigma$

where $\sigma/E = 100\%/\text{sqrt}(E) + 5\%$,

if matching is-

YES: $\Delta E(\text{in-cone}) = +E_{track} - E_{cluster}$

NO: $\Delta E(\text{in-cone}) = +E_{track} - R_{AVE}$ ← photon-charged pion overlap

R_{AVE} = (estimate of average ECAL & HCAL response to charged hadron)

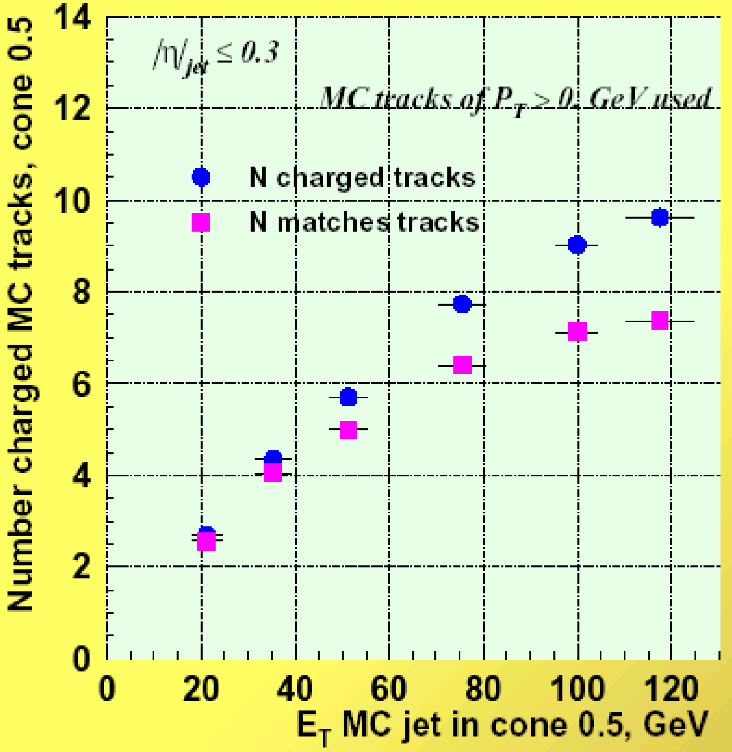
1) Identify whether hadron interaction started in ECAL or HCAL by checking energy in crystals.
2) estimate true energy deposit in ECAL and HCAL using average longitudinal shower shape.
3) estimate ECAL and HCAL response, R_{AVE} (see page 11)

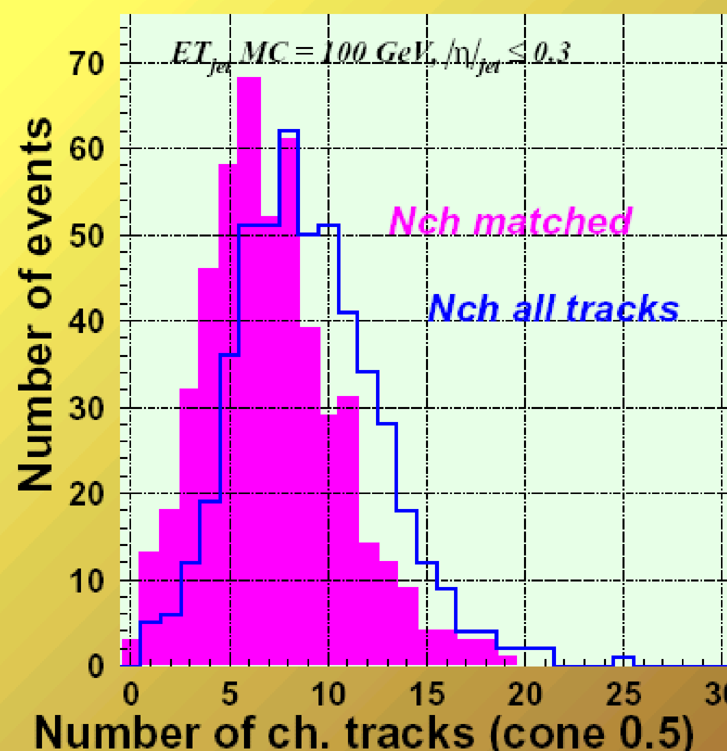
Track – Cluster Match

matching condition: $-\sigma < E_{track} - E_{cluster} < 2\sigma$

where

$\sigma/E = 100\%/\mathrm{sqrt}(E) + 5\%$
Cluster = 3x3 crystals + 3x3 HCAL tower





Estimation of Calorimeter Response

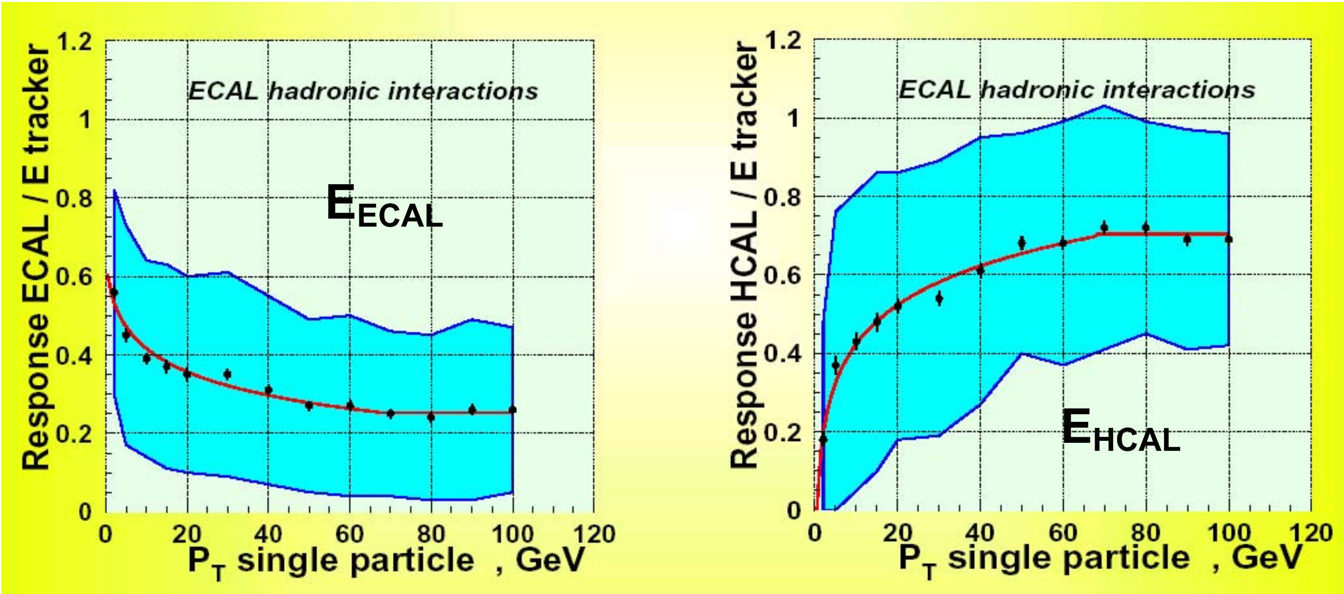
1) Simple average

	Particles interact in ECAL	Particles not interact in ECAL
R_{ECAL}	$E_{Track}*0.4/(e/\pi)_{ECAL}$	E_{MIP}
R_{HCAL}	$E_{Track}*0.6/(e/\pi)_{HCAL}$	$(E_{Track}-E_{MIP})/(e/\pi)_{HCAL}$

$(e/h)_{ECAL}=1.60$, $(e/h)_{HCAL}=1.39$

2) Library of response

GEANT3 simulation for pion interactions started in ECAL.



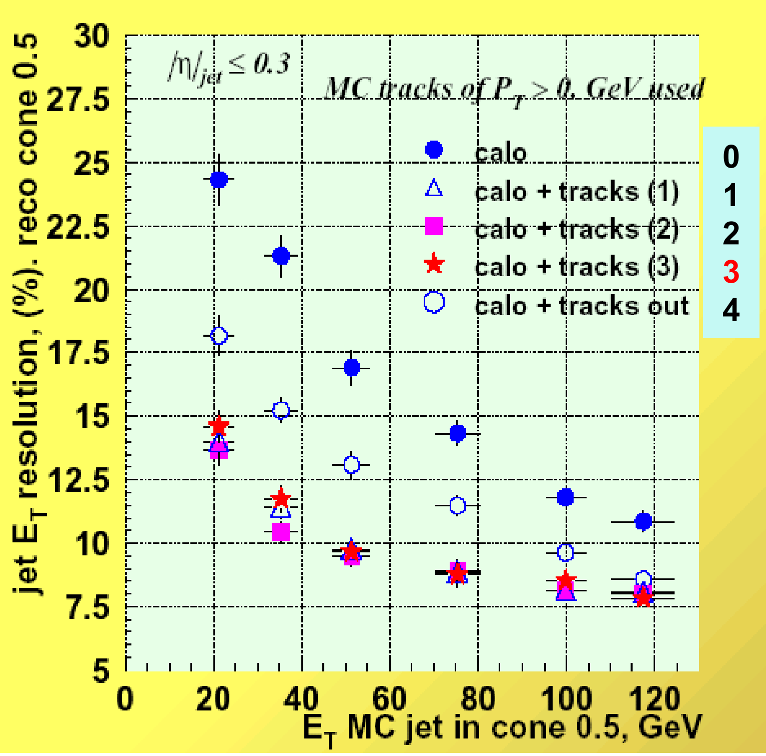
Using Tracks (#5)
Resolution & E_T Scale

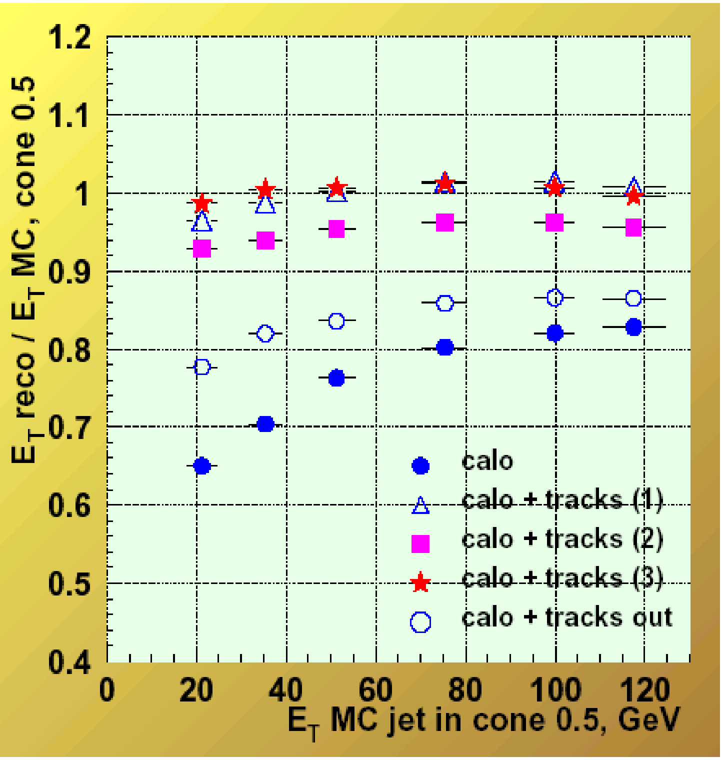
Resolution

20GeV 24% → 14%
100GeV 12% → 8%

E_T Scale

< 2% in 20-20GeV



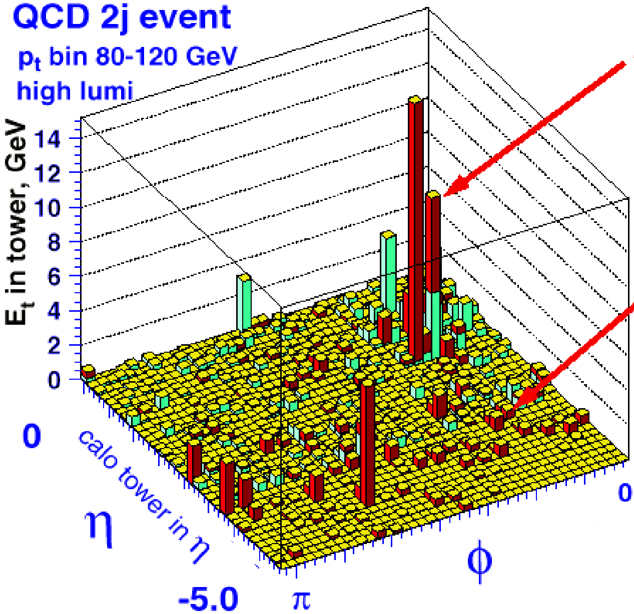


0: no correction (calorimeter only) 1: calo response - simple average 2: calo response – library
3: full correction (library of response, track-cluster match, out-of-cone tracks)
4 out-of-cone tracks correction only

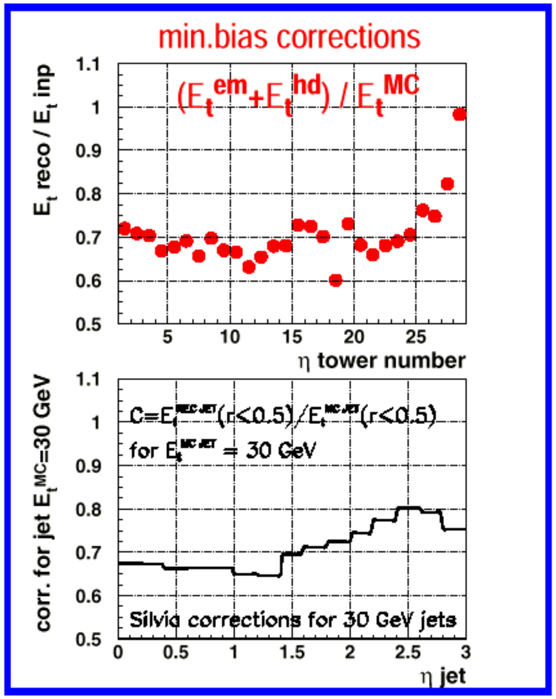
MET
(Missing Transverse Energy)

Extension of the simple jet energy correction (#1) to MET.
$MET(corr) = MET(calo) + \Sigma\{\Delta E_T(\text{jet corr})_{IN}\} + \Delta E_T(\text{min-bias corr})_{OUT}$

Energy scales for MET



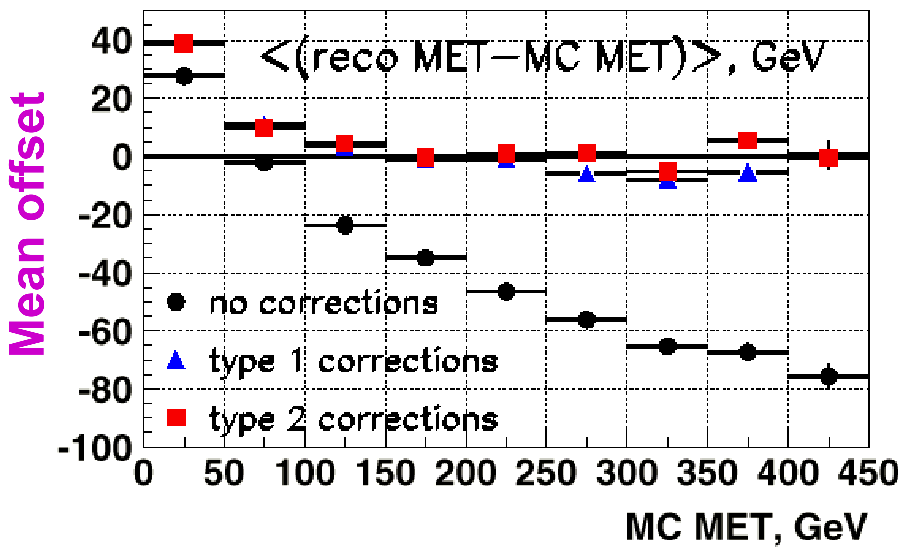
Out of cone corr. uses weights for jet(30GeV) corr.

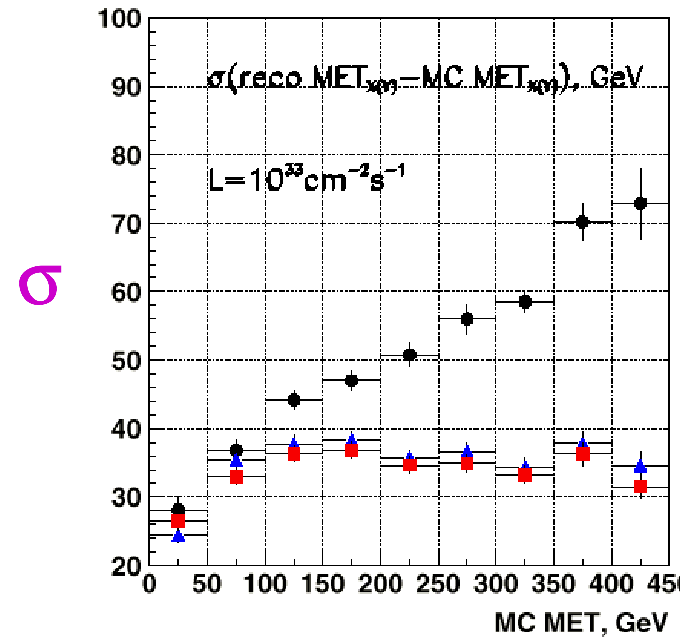


Corrections
- Type 1: Jet corr.
- Type 2: Jet corr. + out of cone corr.

Corrected MET for SUSY

SUSY event: multi jets + MET





An extension of the simple jet energy correction improves also MET energy scale and resolution.

Next: Extend "energy flow" algorithm to MET.

Conclusions

Various algorithms to improve jet energy scale and resolution have been tested for CMS.

- **Simple mapping of jet response in η-E_T space will be used in Level 1 & HLT trigger, and offline.**
- **Large improvement with correction using tracks.**
  - Resolution 20GeV: 24% → 14%
100GeV: 12% → 8%
  - Energy scale <2% in 20-120GeV

Extensions of jet energy corrections to MET look promising.

Our next step is

- **Apply those corrections to various physics processes (with complicated event structure) and test its performance.**
- **Do more detailed analysis and fine tuning.**
- **Extend "energy flow" algorithm to MET.**